Senior Thesis

DETECTION OF A VERTICAL FAULT IN MORGAN COUNTY BY INTERPRETATION OF BRINE CHEMICAL ANALYSES OF THE WHIRLPOOL SANDSTONE

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Abstract

Brines from the Whirlpool Sandstone (Silurian) in Morgan, Muskingum, and Ashtubula counties are enriched in Ca and Sr, but depleted in Na, K, and Mg relative to sea water. This result indicates that chemical reactions such as dolomitization and secondary feldspar formation have occurred. The brines of the Whirlpool Sandstone are resolvable into three components: meteoric water, Na-enriched brine and Ca-enriched brine. One brine sample was discovered to be anomalous. It appears to have originated from the Rose Run Formation located 1,500 feet below the Whirlpool Sandstone. The anomaly implies the existence of a vertical fault or fracture in Morgan County.

Introduction

Brines are located in the subsurface and are usually found below gas and oil deposits. These brines may be used to identify chemical reactions that have affected their chemical compositions by means of which brines can be characterized. This study is based on the chemical analyses of seven brine samples from the Whirlpool Sandstone (Silurian) in Morgan, Muskingum, and Ashtubula counties of Ohio (Table 1).

The goal of this research is to interpret the chemical compositions of the brines in the Whirlpool Sandstone by use of a mixing and dilution model. The results of this interpretation are expected to yield the chemical compositions of the brine components and to identify anomalous brines that do not fit the mixing and dilution model.

Table 1. Chemical analysis of brine samples from the Whirlpool Sandstone (Medina Formation), Morgan County, Ohio. Concentrations in milligrams per liter. (mg/L).

Sample number	1	2	3	4	5	6	7
Well No.	49-88	57-88	9-85	10-85	11-85	12-85	50-88
Na	76200	67400	71800	61800	77000	77000	73600
K	2030	1360	1780	3170	1930	2050	2150
Mg	3920	4570	4690	7630	4110	4110	4640
Ca	36900	36500	36000	50900	35200	35600	39000
Sr	1250	1180	1500	1850	1470	1480	1390
Li	74	44	66	78	80	81	76
Fe	187	268	236	52	332	287	216
I	34	19	28	19	30	30	32
Br	2380	1830	1920	2220	2120	2160	2680
Cl	195000	188000	186000	209000	192000	192000	200000

Chapter 1

LOCAL GEOLOGY

The Whirlpool Sandstone is Early Silurian in age. It rest above the unconformable boundary between the Ordovician and Silurian systems. The Whirlpool Sandstone is sheet like in its form with an average thickness of 83 feet. It is only found in outcrop along the Niagara escarpment in New York and Ontario, Canada.

In the study area in Morgan County, the Whirlpool Sandstone is approximately 4,400 feet below the surface (Collins, 1943). the Whirlpool Sandstone is made up almost entirely of quartzose sand grains. The grains may be white, pink, or gray. Modal analyses reported by Fisher (1984), "reveal 90% detrital quartz and silica, 8% clay, and 2% accessory minerals." The mineral composition is important because quartz is unreactive and therefore the brine is not interacting with the rock. Seyler (1982) describes the sandstone as "clean, well rounded, and well sorted." Sand grains of the Whirlpool Sandstone range in texture from very coarse grained to coarse to medium grained (Pees, 1986). Seyler (1982) noted "that the Whirlpool is a second or multicycle sandstone composed primarily of quartz grains originally derived from igneous and metamorphic terranes". The average porosity of the Whirlpool Sandstone ranges from 7.03 percent to 5.5 percent.

Chapter 2

METHODS

Five of the seven brine samples used in this study originated from Morgan County identified in Figure 1. The other two samples are from Muskingum and Ashtabula counties. The depth at which the samples were obtained ranges from 3055 feet to 5075 feet (Table 2). The locations of the wells in Morgan County are identified by sample number in figure 2.

Comparison to Sea Water

The samples were first compared with sea water that had experienced evaporative concentration. The concentration of two elements in sea water and the brine concentrations were plotted on the same diagram. A line was then drawn from the origin through the data point representing sea water. Five plots were made comparing the concentration of K, Mg, Sr, Na, and Ca versus the concentration of Cl (Figure 3). Brines above this line were considered to be enriched in the element plotted as the ordinate relative to sea water, while brines below this line were considered to be depleted relative to sea water. Cl is conservative for the purposes used.

Mixing and Dilution

The hypothesis was tested that the brines had formed by the mixing of two or more components. This was done by plotting the concentrations of Ca, Na, K, Cl, and Mg versus each other for a total of twenty-one different diagrams. These were used to determine whether the brines were mixtures of two or more components

Figure 1. Outlined Ohio counties from which brine samples orginated.

Table 2. Description of well locations and the recovered brines' physical and chemical properties.

Well No.	49-88	57-88	9-85	10-85	11-88	12-85	50-88
Formation	Clinton -Medina	Clinton -Medina	Medina	Medina	Medina	Medina	Medina
County	Musking-um	Ashta-bula	Morgan	Morgan	Morgan	Morgan	Morgan
Township	Blue Rock	Plymouth	Malta	Penn	Meigs-ville	Meigs-ville	Bloom
Section	10	--	15	11	20	20	9
Lot	--	54	--	--	--	--	--
Permit No.	4028	3685	3693	2200	1834	1834	2031
Well type*	P	P	P	P	P	P	P
Depth(ft)	4293	3055	4720	4819	5075	5075	4544
Sampling* Method	WH	WH	WH	WH	WH	T	WH
Specific Gravity	1.2174	1.2082	1.2059	1.2335	1.2121	1.2136	1.2232
T.D.S	328400	310200	307300	346200	317800	320500	333900
Temp.	14 C	14 C	13 C	17 C	16 C	ND*	16 C
Alk.	37	54	86	65	55	ND*	25
pH	5.1	5.3	4.7	5.78	5.52	ND*	5.03

*P- pumping well , WH- wellhead, T- tank, ND- not determined.

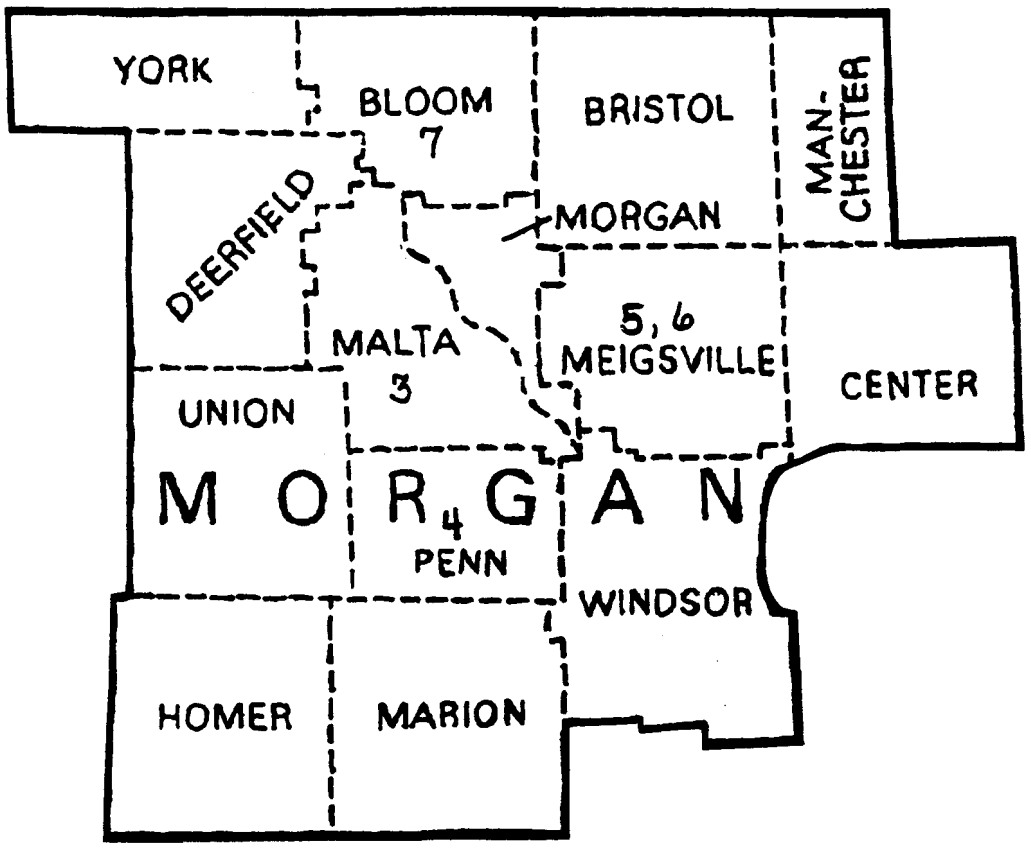


Figure 2. Locations of wells in Morgan County.

followed by dilution with meteoric water. If all of the samples formed by dilution of a single brine, then they should define a straight line moving toward the origin. If, however, the samples are mixtures of two brines, they should fit a line that does not approach the origin. If these mixtures were subsequently diluted with meteoric water, the samples form a cluster of points.

In that case, dilution lines are fitted by first drawing a line from the origin through the point farthest to the right, then from the origin through the point farthest to the left. These lines enclose the dilution area. A third line is then drawn through the farthest points which form a line and enclose all other points within a triangle of mixing. The far corners of the mixing triangle are then used to estimate the chemical composition of the original brines.

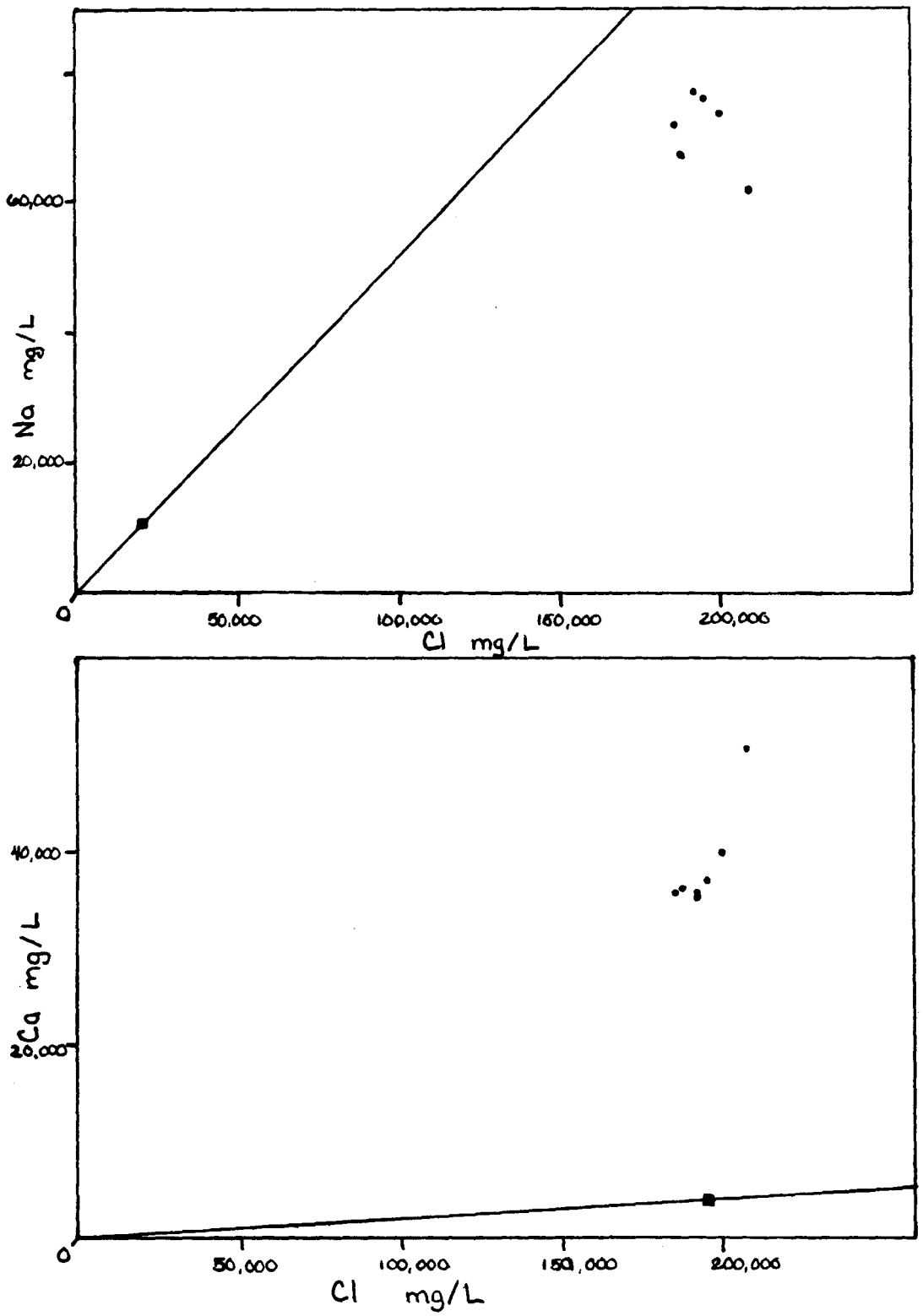


Figure 3. Plots comparing the concentrations of Na and Ca versus Cl with sea water that had experienced evaporative concentrations.

■ Sea Water • Whirlpool Sandstone Brines

Chapter 3

RESULTS AND INTERPRETATION

Comparison to Sea Water

The brine samples from the Whirlpool Sandstone are enriched in Ca and Sr, but they are depleted in Na, K, and Mg relative to sea water (Table 3). These results indicate that the chemical composition of the brines have been changed by chemical reactions with rocks with which they came in contact before they entered the Whirlpool Sandstone.

The apparent loss of Mg and gain of Ca may be attributed to the dolomitization of limestone. The process of dolomitization involves replacing a Ca atom in calcite with a Mg atom from the brine. When this exchange occurs, Mg is removed from the brine causing its depletion, whereas Ca enters the brine causing its enrichment as illustrated below.

$$2CaCO_3 + Mg^{2+} \longrightarrow CaMg(CO_3)_2 + Ca^{2+} \qquad (1)$$

the apparent loss of K and Na may be due to the formation of secondary feldspars. IN this process, kaolinite is altered to form either albite (Na-feldspar) or adularia (K-feldspar). This reaction involves loss of either Na or K from the brines according to the reactions.

$$Al_2Si_2O_5(OH)_4 + 2K^+ \longrightarrow \underset{\text{(adularia)}}{2KAlSi_3O_8} + 9H_2O + 2H^+ \qquad (2)$$

Table 3. Calculation of enrichment factors for the major elements in the brines compared to concentrated seawater at the same chloride concentration as the brines.

Element mg/L	Average Concentration in brines	Sea Water Concentration (extrapolated)	Enrichment or Depletion factor f= brine conc. / sea water conc.
Na	72,114	107,762	0.67
K	2,067	3,981	0.52
Mg	4,810	12,872	0.37
Ca	38,714	4,121	9.4
Sr	1,446	76	19.0
Cl	194,571	194,571	1.0

Note: If f> 1, the brine is enriched in the element compared to the concentration in sea water.
If f< 1, the brine is depleted in the element compared to the concentration in sea water.
If f= 1, the brine has the same concentration of the element compared to the sea water concentration.

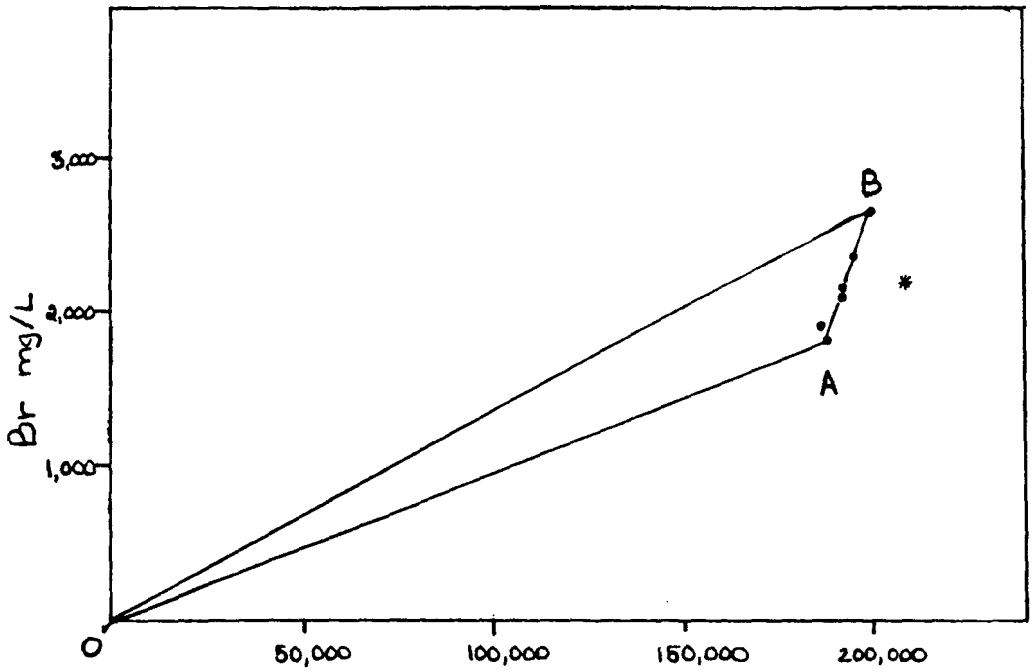
$$Al_2Si_2O_5(OH)_4 + 2Na^+ \longrightarrow \underset{\text{(albite)}}{2NaAlSi_3O_8} + 9H_2O + 2H^+ \quad (3)$$

The brine samples demonstrated this depletion in Na and K. The formation of secondary feldspars occur in dolomite, which is commonly found in Ohio. Mensing et al. (1984) noted the formation of these secondary feldspars in the basement rocks of Ohio.

Mixing and Dilution

In order to determine whether the chemical composition of the brines can be explained by mixing and dilution, a triangle of mixing was constructed in Figure 4. compared to the other brine samples, sample four from Penn Township in Morgan County is lower in Na concentration, but higher in K, Mg, Ca, and Cl. Due to its unexpected chemical composition it was left out of the mixing triangle. The chemical composition of this sample will be discussed in the next chapter.

The concentration of elements in the component brines are recorded in Table 4. The average was calculated for each element in brines A and B, and the standard deviation of the mean was calculated and listed in the table with the percent error. The results in Table 4 shoe that brine A has a higher Na concentration, while brine B has higher concentration in Ca, K, Mg, Sr, Br, and Cl. We may now refer to brine A as the Na-rich brine and Brine B as the Ca-rich brine. The brines compositions are easily distinguished on the mixing triangle. The percent errors are small with the largest being 7.1 percent. Since the percent errors are small, the estimates made of the components are reliable.



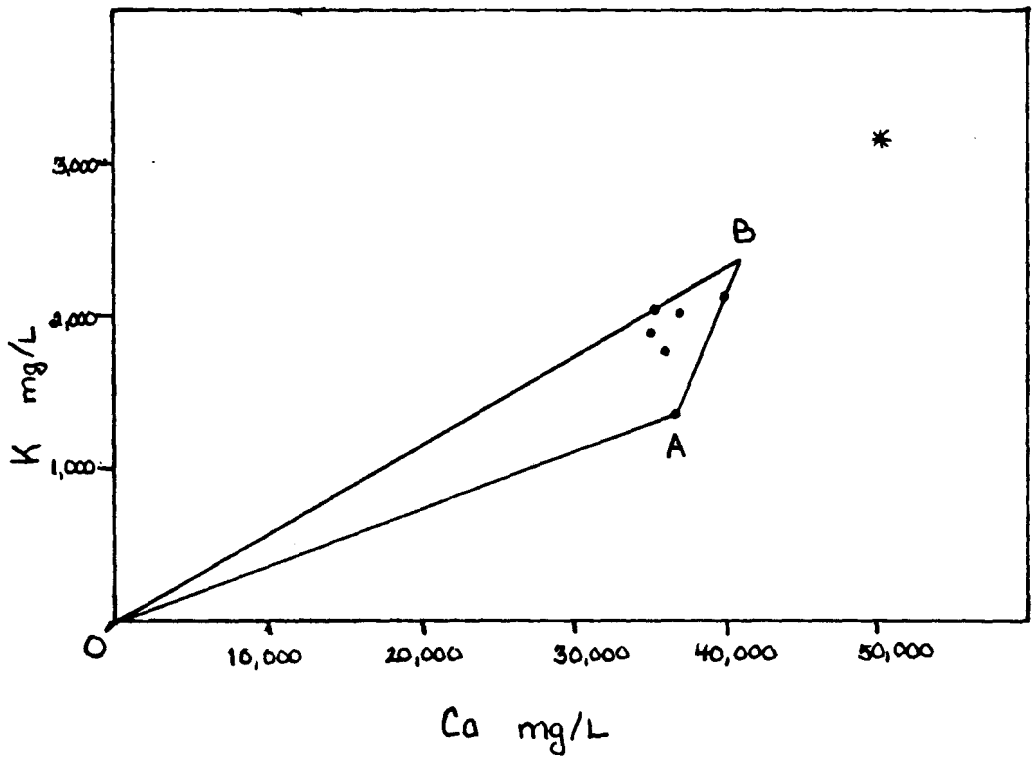


Figure 4. Mixing triangles display evidence for mixture of two brines followed by dilution with meteoric water.
• Rose Run Brine * Sample Four

Table 4. Estimates of the chemical components of component A and component B in mg/L.

Element	Component A	Component B
Na	79,800 2,320, 2.9%	73,000 ± 540, 0.7%
K	1,580 ± 112, 7.1%	2,300 ± 73, 3.2%
Mg	4,150 ± 151, 3.6%	5,300 ±280, 5.3%
Ca	36,600 ± 352, 1.0%	41,300 ± 700, 1.7%
Sr	1,530 ± 22, 1.4%	1,400 ± 42, 3.0%
Cl	189,000 ± 2,140, 1.1%	230,000 ± 13,000, 5.7%
Br	1,940 ± 44, 2.3%	2,700 ± 54, <0.1%

Chapter 4

EVIDENCE FOR THE VERTICAL MIGRATION OF THE ROSE RUN BRINE

Sample 4 (Penn Township in the center of Morgan County) has an anomalous chemical composition because of higher concentrations of K, Mg, Ca, Sr, and Cl than in any of the other brines in the Whirlpool Sandstone. A possible explanation for this anomaly may be that minerals such as calcite and gypsum in the reservoir are dissolving. If this is occurring, we would expect more than one sample in the surrounding area to be affected. A second possibility is that evaporation of the brine is occurring by gas bubbles streaming through the brine in the subsurface. However, evaporation by this process is uncommon and occurs only under specific conditions. A third possibility is that the sample was misidentified, because it may have been taken at greater depth than that of the Whirlpool Sandstone at this location. This is probably not the case since the sample was taken at a depth of 4,819 feet which is close to the average depth of the Whirlpool Sandstone in Morgan County.

Finally, it is possible that sample 4 actually originated from a formation below the Whirlpool Sandstone. When the chemical composition of sample 4 is compared to brines in formations below the Whirlpool Sandstone, it is found to be most similar to brine in the Rose Run Formation (Middle Ordovician). The brines in formation between the Whirlpool Sandstone and the Rose Run Formation all have lower Ca concentrations than sample 4. Although the Rose Run Formation is more than 1,500 feet below the Whirlpool Sandstone,

Figure 5 shows that the concentrations of Na, Ca, Mg, K, and Cl of sample 4 are much more similar to Rose Run Formation brines and differ significantly from the Whirlpool Sandstone brines.

Therefore, brines from the Rose Run Formation may have reached the Whirlpool Sandstone by way of a vertical fault which connects the two formations and may extend into the overlying rock layers. Accordingly, brines from the Rose Run Formation may have locally invaded the Whirlpool Sandstone and other reservoir rocks, thereby causing the local geochemical anomaly recognized in this study.

If waste injection is practiced into the Rose Run Formation, serious consequences for Morgan County residents may ensue. The brines rising from the Rose Run Formation may carry the injected waste back up into the overlying formations. If the surface of even the water table is reached, contamination of water supplies in the surrounding areas may occur. Clean-up of such a mishap would be time consuming and expensive.

The study of the chemical compositions of brines may provide evidence for the existence of faults whose presence may affect the desirability of construction disposal wells in Morgan County and in the surrounding areas.

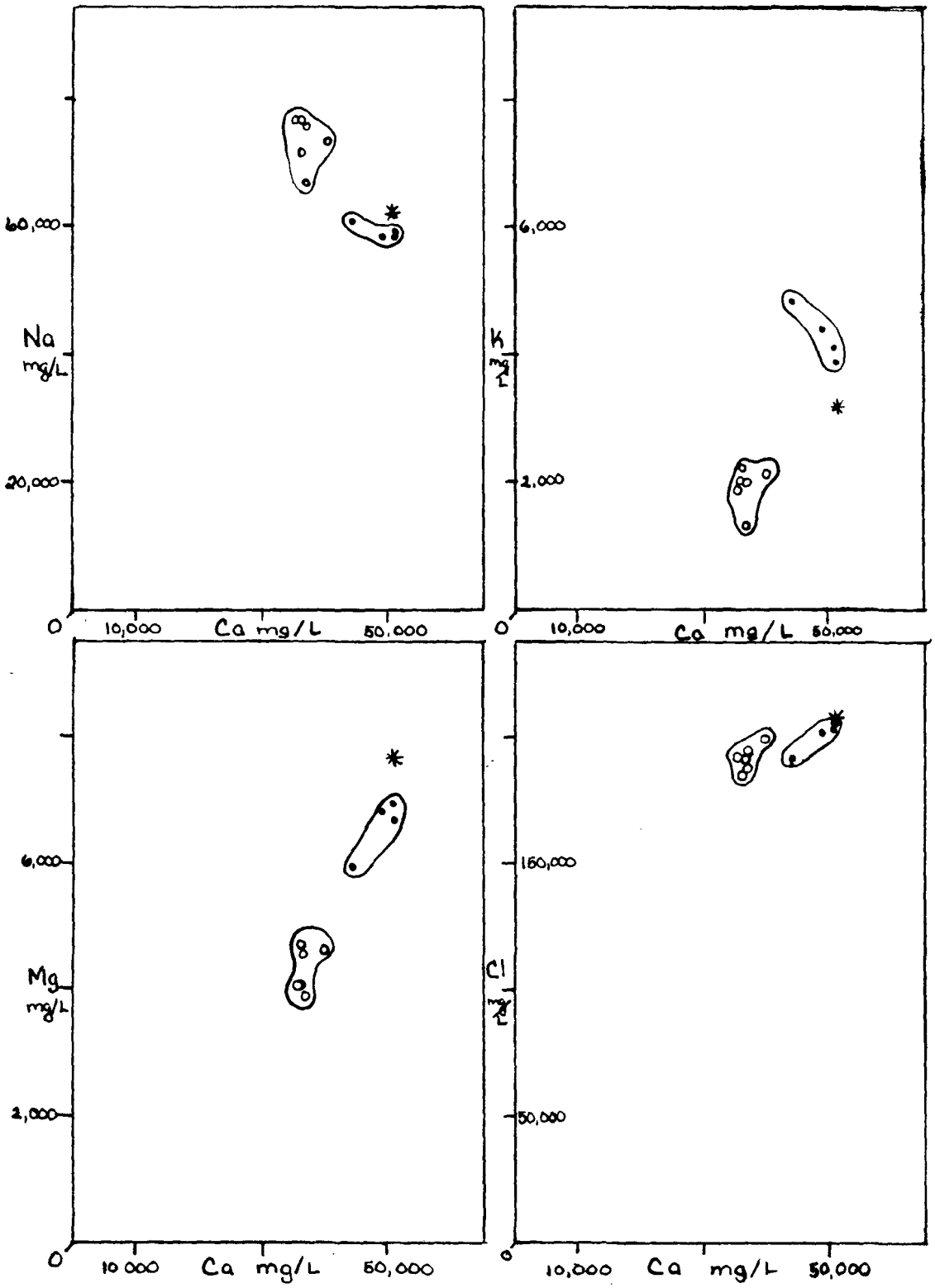


Figure 5. Plots of the brine concentrations of Na, Ca, Mg, and Cl of the Rose Formation, Whirlpool Sandstone, and sample four.

• Rose Run Brines ○ Whirlpool Brines ✱ Sample Four

Conclusion

The Whirlpool Sandstone brine samples are mixtures of two components which have subsequently been diluted by meteoric water. Brine A is considered the Na-rich brine, while brine B is the Ca-rich brine. Sample 4, located in Penn Township of Morgan County at a depth of 4,819 feet below the surface was discovered to be anomalous. The chemical composition of this sample is similar in composition to the brines of the Rose Run Formation located 1,500 feet below the Whirlpool Sandstone. Therefore, brine from the Rose Run Formation appears to be rising into the Whirlpool Sandstone. This can be seen as evidence for the existence of a fault in Morgan County. This fault has not been detected on the surface, most likely because the rocks are covered by outwash. The discovery of this fault is important for the prevention of environmental hazards. If a waste injection well were to be put into the Rose Run Formation in Morgan County, the waste may rise into the overlying rocks. Therefore, this study demonstrates that interpretation of the chemical analyses of brines can be helpful in detecting vertical faults whose presence constitutes a potential environmental hazard.

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